

KINEMATICS OF THE SGRB2(N-LMH) MOLECULAR CORE

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ABSTRACT

Ethyl cyanide ($\text{CH}_3\text{CH}_2\text{CN}$) emission and absorption have been imaged with the Very Large Array (VLA) toward SgrB2(N-LMH) by means of the $5_{15}-4_{14}$ rotational transition at 43.5 GHz ($\lambda \sim 7$ mm). The $1.5'' \times 1.4''$ VLA beam shows two principal sources of ethyl cyanide emission: an unresolved source $\sim 5''$ north of the LMH that is kinematically consistent with simple expansion, contraction, or small-scale turbulence, and the resolved LMH core source itself that shows kinematics indicating an edge-on rotating disk that extends $\geq 3''$ (~ 0.1 pc) in the approximate east-west direction. A search for the $7_{07}-6_{06}$ rotational transition of the amino acid glycine ($\text{NH}_2\text{CH}_2\text{COOH}$) at 43.7 GHz toward SgrB2(N-LMH) gave negative results.

Subject headings: ISM: abundances --- ISM: clouds ---

ISM: individual (Sagittarius B2[N-LMH]) ---

ISM: molecules --- radio lines: ISM

I. INTRODUCTION

The SgrB2 star-forming region is usually the first source searched to detect and identify new large interstellar molecules in our Galaxy. At the SgrB2 North position, i.e., SgrB2(N) which has a spatial extent of $\sim 20''$ in radio continuum emission, there are a number of shell-like and arc-like HII regions with ionization fronts that are brighter toward the southwest (e.g., Gaume et al. 1995). Large saturated molecules such as ethyl cyanide ($\text{CH}_3\text{CH}_2\text{CN}$) appear to be concentrated within an $\sim 5''$ region of SgrB2(N) designated the Large Molecule Heimat (LMH) by Snyder, Kuan, & Miao (1994). We have studied the kinematics of the LMH via ethyl cyanide line emission at ~ 7 mm with the NRAO⁹ Very Large Array (VLA).

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We found that the ethyl cyanide emission has an asymmetric brightness distribution similar to that of arc-like HII regions in the vicinity of the LMH and a strong velocity gradient which suggests a rotating disk.

II. OBSERVATIONS

Simultaneous observations of ethyl cyanide and glycine at ~ 43 GHz were conducted toward SgrB2(N-LMH) with the VLA in 2003 January 25, 27, and 28 in its DnC configuration. The phase center for all observations was $\alpha = 17^{\text{h}}47^{\text{m}}19^{\text{s}}.878$, $\delta = -28^{\circ}22'18''.385$ (J2000), which is coincident with the K2 continuum position given in Liu & Snyder (1999). The primary beam for our observations was $\sim 1'$. The correlator was operated in the Four IF normal mode, and the selection of a 6.25 MHz bandpass yielded 32 spectral channels in two pairs of oppositely polarized IFs. The spacing is 195.313 kHz (~ 1.34 km s $^{-1}$). For each line, the line rest frequency at an assumed LSR source velocity of $+62.5$ km s $^{-1}$ was centered in the ~ 43 km s $^{-1}$ bandpass. Table 1 lists the molecular parameters of the molecules observed: the molecule (col. 1); rotational quantum numbers (col. 2); rest frequency (col. 3); upper energy level E_{u} (col. 4) in Kelvins; line strength S (col. 5); and dipole moment μ_{a} (col. 6) in debye.

Compact radio sources 1700-261 and 1733-130 were used as the phase and bandpass calibrators, respectively. The absolute flux density scale was determined from observations of 3C286 whose 43 GHz flux density is 1.44 Jy (accurate to within 15%) as given by the SETJY routine in AIPS. The bootstrapped flux densities of 1700-261 and 1733-130 were 0.68 and 4.50 Jy, respectively, and showed satisfactory repeatability at each observing epoch. Antenna gains were derived from 1700-261 observations at ~ 20 min intervals, and the phases were self-calibrated every 20 seconds using the strong continuum emission.

Continuum subtraction was performed in the u,v plane and data cubes of the total intensity line emission were created by averaging the right and left circularly polarized visibilities. The naturally weighted synthesized beam resulting from the DnC configuration was $\sim 1.5'' \times 1.4''$. Relevant parameters for the emission and absorption regions such as flux density, centroid position, and size were extracted from each spectral (velocity) channel using the AIPS tasks SAD and JMFIT. SAD was used to fit two-dimensional Gaussians to all features greater than 3σ (~ 8 mJy beam $^{-1}$) within each spectral channel of the image cube

containing the ethyl cyanide emission. Similarly, JMFIT (which does a better job on the more diffuse low-level emission) was used on the ethyl cyanide absorption regions with a slightly lower threshold of 2σ (~ 5 mJy beam $^{-1}$).

3. RESULTS AND DISCUSSION

A surprising number of distinct ethyl cyanide emission and absorption features were detected toward SgrB2(N-LMH). These features are shown in the velocity channel images of Figure 1. Figure 2 is the sum of all velocity channel images superimposed on a grey-scale representation of 43.5 GHz continuum. Figure 2 shows that the bulk of the ethyl cyanide emission resides in the LMH hot core source itself which is in proximity to crosses marking ultracompact HII regions K2 and K3 (see K designations in Gaume et al. 1995). Approximately 5" north of the LMH, there is a secondary ethyl cyanide emission source which is coincident with the quasi-thermal methanol emission core "h" (Mehring & Menten 1997). Additionally, a weak ethyl cyanide emission source west of the LMH is coincident with the methanol maser emission source designated "2" (Houghton & Whiteoak 1995). Extended ethyl cyanide absorption is present in the vicinity of K6; the continuum here was shown to be optically thin free-free emission by Mehring & Menten (1997). Figure 3 shows an unresolved source of ethyl cyanide absorption coincident with the K3 ultracompact HII region in the LMH. We also report the detection of ethyl cyanide in absorption at SgrB2(M) which is too far south to be seen in our figures.

Rotational temperature limits for ethyl cyanide emission and absorption regions of interest in the vicinity of the LMH can be estimated from high resolution continuum data. Gaume et al. (1995) observed continuum emission regions K1-K6 with a beam size of $0.27'' \times 0.23''$ at 22.4 GHz. Continuum brightness temperatures derived from these high resolution data place more severe limits on molecular rotational temperatures of ethyl cyanide than our lower resolution (i.e., $1.5'' \times 1.4''$ beam) continuum data at 43.5 GHz can provide. For example, using the 22.4 GHz peak flux densities in Table 2 of Gaume et al. (1995), we corrected these data for emission at 43.5 GHz and calculated continuum

brightness temperatures which indicate $250 \text{ K} < T_{\text{ROT}} < 1000 \text{ K}$ for the ethyl cyanide emission assumed to lie in front of the LMH HII regions (i.e., K1, K2, and K3); similarly, ethyl cyanide $T_{\text{ROT}} < 190 \text{ K}$ in the direction of ethyl cyanide absorption near K6.

To aid in the interpretation of the kinematics, LSR velocity information for each distinct ethyl cyanide feature found in the image cube is shown via colored symbols in Figure 3. The top panel spectrum shows individual ethyl cyanide emission and absorption features with color-coded LSR velocities that range from $+49$ to $+76 \text{ km s}^{-1}$. In the top panel, a circle symbol represents the strongest emission features found in each velocity plane while apex upward triangle symbols represent lesser strength emission features; a square symbol is used to represent the emission coming from the source $\sim 5''$ north of the LMH; and an apex downward triangle symbol represents absorption. The areal size of a filled symbol is proportional to the logarithm of the total flux found in a given ethyl cyanide feature and the coordinates of each symbol plotted in the bottom panel of Figure 3 represents the centroid position of each feature. In Figure 3, the unresolved emission source $\sim 5''$ north of the LMH shows no appreciable velocity gradient since most of the square symbols are spatially coincident -- a situation consistent with simple expansion, contraction, or small-scale turbulence along the line of sight (Goldreich & Kwan 1974). In contrast, it is apparent that a complex velocity field exists across spatial extent of the LMH emission which is in proximity to the K2 ultracompact HII region. Of particular note is the arc-like morphology of the LMH ethyl cyanide source in Figure 3. This morphology is consistent with that of previously studied arc-like structures in radio continuum in SgrB2(N) (Gaume & Claussen 1990; Gaume et al. 1995). Below, we offer an explanation of this spatial and LSR velocity complexity for the LMH and its vicinity.

Figure 4 is an expanded view of the strongest ethyl cyanide emission features found in each velocity plane, showing that the resolved LMH core source has a strong velocity gradient in the approximate east-west direction (east side approaching and the west side receding). The spatial and LSR velocity information shown in Figure 4 suggests a slightly

distorted, edge-on rotating disk of ethyl cyanide which extends $\geq 3''$ in the east-west direction. The disk feature contains most of the ethyl cyanide mass in the field and is embedded in an arc-like shaped nebula of less pronounced ethyl cyanide emission. A similar global "wind-blown" shape is seen in the complex of HII regions shown in Figure 2. Lesser emission and absorption features of ethyl cyanide are shown in Figure 3. While such weaker emission and absorption features may simply be ambient cloud material, another possibility is that these features arise in gas that has been ablated from the disk by an outflow whose source is in the approximate direction of K1. As the ablated ethyl cyanide gas flows northeast, it cools and absorbs against the free-free continuum emission. As shown in Figure 3, the LSR velocity of these features is in the range of 60-65 km s⁻¹ which is characteristic of the LMH source for a number of large molecules (e.g. Liu & Snyder 1999).

A disk interacting with an outflow may provide a useful model for other molecules whose spatial and LSR velocity distributions are not well fit by simple rotation, bipolar flow, or expansion (e.g., Gaume & Claussen 1990; Miao & Snyder 1997; Liu & Snyder 1999). On the other hand, cyanoacetylene (HC₃N) observations of SgrB2(N) show evidence for velocity gradients both north-south and east-west; in the east-west case the gradient direction (see Figs. 3 & 4 of Lis et al. 1993) is consistent with that of ethyl cyanide. However, Lis et al. interpret the HC₃N east-west velocity gradient as outflow and the north-south velocity gradient as rotation. Moreover, the Reid et al. (1988) study of H₂O maser proper motions in SgrB2(N) produced a three-dimensional uniform outflow model whose systematic residuals suggest possible rotation. However, the direction of the H₂O rotation gradient seen in projection is opposite that of ethyl cyanide. The simplest explanation is that ethyl cyanide delineates a rotating disk while the H₂O maser velocities are dominated by an outflow which itself may be rotating.

For a rotating molecular disk, the dominant motion of the ethyl cyanide gas is likely circular rotation in the plane of the disk. Using the circular rotation approximation for a

disk seen edge-on at a distance of 7.1 kpc (Reid et al. 1988), we calculate that the total mass of the LMH star forming region is $\sim 2600 M_{\odot}$ for a disk diameter of 3" (~ 0.1 pc) and a circular velocity of 15 km s^{-1} as suggested by Figure 4. Liu and Snyder (1999) obtained a mass of $\sim 1400 M_{\odot}$ for the LMH based on BIMA Array data of the $10_{1,10} - 9_{1,9}$ transition of ethyl cyanide whose appearance in their Figure 2(b) resembles a torus. With absorption at K3 that dominates emission, our Figure 3 ethyl cyanide data suggest the reason for the torus shape previously reported by Liu & Snyder (1999) for ethyl cyanide emission at 86.8 GHz. The 86.8 GHz ethyl cyanide is absorbing against all three ultracompact sources (i.e., K1, K2, and K3) which lie in an approximate straight line on the sky; this geometry would account for apparent reduction in the emission intensity along the K1-K3 line that runs through the middle of the ethyl cyanide region, thereby suggesting a torus shape for the emission due to the distorting effects of competing absorption.

The ethyl cyanide emission source "h" shown in Figure 3 $\sim 5''$ north of the LMH was also detected and briefly mentioned in Liu & Snyder (1999). Figure 1 shows that the emission associated with source "h" has a velocity centered near 72 km s^{-1} which is the characteristic LSR velocity of a few large molecules first detected with single dish telescopes such as glycolaldehyde and ethylene glycol (Hollis et al. 2000, 2002), and vinyl alcohol (Turner & Apponi 2001). Thus, source "h" is an important molecular source where these particular large molecules probably have an enhanced local concentration. In the case of glycolaldehyde, the bulk of its emission appears spatially extended on a scale as large as $60''$ (Hollis et al. 2001).

During the course of this work we also conducted a deep search for the lowest energy form of glycine (conformer I) in its $7_{07} - 6_{06}$ transition, obtaining a 3σ peak intensity limit of $< 1.8 \text{ mJy beam}^{-1}$ from a spectrum extracted in a naturally weighted beam size of $1.5'' \times 1.4''$ at the position of K2 in the LMH. Using a rotational temperature of 170 K for the LMH (e.g., see Pei, Liu, & Snyder 2000) and equation (5) of Hollis et al. (2003), a beam-averaged column density limit of $< 1.4 \times 10^{17} \text{ cm}^{-2}$ is obtained for glycine with an assumed

line width of $\sim 10 \text{ km s}^{-1}$ (e.g. see Liu & Snyder 1999). If glycine exists in the LMH, it is below this detection limit, or it is spatially more extended than other large molecules in this source, or it may be in its high energy form (conformer II). In the glycine bandpass we detected the unidentified line, U43751.5. This emission was imaged at K2 and K3 in the LMH and had a peak intensity of $\sim 7 \text{ mJy beam}^{-1}$ at position K2.

In summary, ethyl cyanide emission and absorption features have been imaged with the VLA toward Sagittarius B2 by means of the $5_{15}-4_{14}$ rotational transition at 43.5 GHz. In the vicinity of the SgrB2(N-LMH) hot core, the strongest ethyl cyanide emission features are consistent with a rotating molecular disk seen approximately edge-on. Interior to the disk we obtain a total mass of $2600 M_{\odot}$ for this star-forming region. We present kinematical and morphological evidence that the molecular disk is interacting with an unseen source to the southwest. We have for the first time detected ethyl cyanide in absorption toward SgrB2(M). We also conducted a search for the $7_{07}-6_{06}$ transition of conformer I glycine but our results were negative.

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TABLE 1

Ethyl Cyanide and Glycine Molecular Parameters

Molecule (1)	Transition $J'_{K-K+} - J''_{K-K+}$ (2)	Frequency (MHz) (3) ^a	E_u (K) (4)	S (5)	μ_a (D) (6)
Ethyl Cyanide ^b	$5_{15} - 4_{14}$	43516.198(4)	7.379	4.800	3.85
Conf. I Glycine ^c	$7_{07} - 6_{06}$	43753.841(28)	8.657	6.851	0.911

^aUncertainties in parentheses refer to the least significant digit(s) and are 2σ .

^bDipole moment (Lovas 1982); rest frequency calculated in this work.

^cDipole moment (Lovas et al. 1995); rest frequency calculated in this work.

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FIGURE CAPTIONS

Fig. 1 - Velocity channel images of the $5_{15}-4_{14}$ transition of ethyl cyanide toward SgrB2(N-LMH). The LSR velocity in km s^{-1} is labeled in each panel. Contour levels are -3, -2, -1, 1, 2, 4, 8, 16, and 32 times $6.5 \text{ mJy beam}^{-1}$. Dashed contours represent negative intensities. Channel spacing is 195.313 kHz ($\sim 1.34 \text{ km s}^{-1}$). The $1.5'' \times 1.4''$ naturally weighted beam size is shown in the lower left of the top right panel.

Fig. 2 - Contour image of the integrated intensity of the $5_{15}-4_{14}$ transition of ethyl cyanide toward SgrB2(N-LMH) overlaid on a gray scale image of continuum emission at 43.5 GHz . Contour levels are -4, -3, -2, -1, 1, 2, 4, 8, 16, 32, and 64 times $32 \text{ mJy beam}^{-1} \text{ km s}^{-1}$. Dashed contours represent negative values. Individual channels were blanked at the 3σ level ($\sim 8 \text{ mJy beam}^{-1}$) prior to integration from 46.4 to 78.6 km s^{-1} . The gray scale wedge units are mJy beam^{-1} . Reference position crosses are plotted for ultracompact HII regions K1-K6 and sources "h" and "2". The $1.5'' \times 1.4''$ naturally weighted beam size is shown in the lower left.

Fig. 3 - LSR velocity structure of absorption and emission features of the $5_{15}-4_{14}$ transition of ethyl cyanide toward SgrB2(N). The top panel is the spectral line profile of absorption and emission features. Velocity color-coding is used to show the spatial location of material at each velocity when used in conjunction with the bottom panel. The bottom panel is the spatial distribution of absorption and emission features with color-coded velocities matching the increments in the top spectral line profile. Reference position crosses are plotted for HII regions K1-K3, K5, K6, and methanol source "h". Coordinates are relative to K2. Also included in the bottom panel are dashed contours showing the maximum absorption and solid contours showing the maximum emission for ethyl cyanide at every pixel location. Contour intervals are -2, -1.5, -1, 1, 2, 4, 8, and 16 times 8 mJy beam^{-1} (the 3σ noise level).

Peak emission and absorption flux densities are $206 \text{ mJy beam}^{-1}$ and $-22 \text{ mJy beam}^{-1}$, respectively. The relative size of the symbols used for plotting an ethyl cyanide feature is proportional to the logarithm of the flux density.

Fig. 4 - LSR velocity structure of the strongest emission features of the ethyl cyanide $5_{15}-4_{14}$ transition found in the LMH hot core. This is an expanded view of the same data plotted in Figure 3 whose caption applies here. The strong velocity gradient shown suggests a rotating molecular disk seen approximately edge-on (see text).







